Climate Change and Ecological Impacts at Saguaro National Park, Arizona

Patrick Gonzalez

Natural Resource Stewardship and Science, National Park Service, Washington, DC

May 10, 2013

Introduction

Greenhouse gas emissions from vehicles, power plants, deforestation, and other human activities have increased temperatures around the world and changed other aspects of climate (IPCC 2007a). Published field research shows that climate change is also altering ecosystems by shifting biomes, contributing to species extinctions, and causing numerous other changes (IPCC 2007b). To assist Saguaro National Park (NP) integrate climate change into resource management, this report presents results of spatial analyses of historical and projected climate and a summary of published scientific findings on ecological changes related to climate change.

Historical Climate Changes

From 1901 to 2002, mean annual temperature increased across the western United States (U.S.) (Figure 1; Gonzalez et al. 2010) and showed a statistically significant increase in the area that includes Saguaro National Park (NP) (Figure 2, Table 1). From 1948 to 2012, mean annual temperature also showed a statistically significant increase at the Tucson airport weather station (Figure 2). From 1901 to 2002, precipitation decreased across the southwestern U.S. (Figure 3; Gonzalez et al. 2010), although it showed no statistically significant trend in the Saguaro NP area or in the 1948-2012 time series at the Tucson airport weather station (Figure 4).

Historical Ecological Changes

Field measurements from Saguaro NP and the surrounding area have contributed to the detection of statistically significant 20th century ecological changes attributable to climate change. Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor controlling burned area, even during periods of active fire suppression (Littell et al. 2009). Climate change has also caused bark beetle outbreaks leading to the most extensive tree mortality across western North America in the last 125 years (Raffa et al. 2008). Climate change has also shifted the winter ranges of a set of 254 bird species northward across the U.S. at an average rate of 0.5 ± 2.4 km y^{-1} from 1975 to 2004 (La Sorte and Thompson 2007).

Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007). The three main IPCC greenhouse gas emissions scenarios are B1 (lower emissions), A1B (medium emissions), and A2 (higher emissions). Actual global emissions are on a path above IPCC emissions scenario A2 (Le Quéré et al. 2013, Raupach et al. 2007).

For the three main IPCC emissions scenarios, projected 21st century temperature in the Saguaro NP area could increase three to five times the amount of historical 20th century warming (Table 1, Mitchell and Jones 2005, Gonzalez et al. 2010). The average of ensembles of general circulation models (GCMs) of the atmosphere project decreased precipitation for the Sagauaro NP area under all three IPCC emissions scenarios (Table 1). For emissions scenario A2, 14 out of 18 GCMs project decreases in precipitation (Figure 5; historical average from Mitchell and Jones 2005, Hijmans et al. 2005; projections from IPCC 2007, Tabor and Williams 2010, Conservation International; analysis by P. Gonzalez).

Projections indicate potential changes in the frequency of extreme temperature and precipitation events. Modeling under emissions scenario A2 projects 30 to 35 more days with a maximum temperature $> 35°C$, 15 to 20 fewer days with a minimum temperature $< 0°C$, and 10 to 15 more consecutive days with precipitation < 3 cm between the periods 1980-2000 and 2041-2070 (Kunkel et al. 2013).

Projected Ecological Vulnerabilities

Analyses of ten populations of saguaro cactus (*Carnegiea gigantea*) in the national park and other sites across the Sonoran Desert from 1959 to 2005 did not reveal direct relationships of growth, recruitment, or mortality to climate change, although moister conditions can increase regeneration (Pierson et al. 2013). Likewise, analyses of invasion patterns of buffelgrass (Pennisetum ciliare L.) in the Santa Catalina Mountains from 1980 to 2008 found no significant correlation to climate, although warm winters can favor germination and establishment (Olsson et al. 2012). Analyses of vegetation plots in the national park and other protected areas indicate possible vulnerability of foothill palo verde (*Parkinsonia microphylla*), ocotillo (*Fouquieria splendens*), and creosotebush (Larrea tridentata) to increased aridity (Munson et al. 2012).

Table 1. Historical and projected climate trends for the area that includes Saguaro NP (Mitchell and Jones 2005, IPCC 2007, Gonzalez et al. 2010) and at the Tucson airport weather station (data National Oceanic and Atmospheric Administration). Historical climate and projections for IPCC emissions scenarios B1 and A1B calculated for the 50 x 50 km pixels that include the park (Gonzalez et al. 2010). Climate under emissions scenario A2 calculated for the 4 x 4 km pixels that include the park (data from Conservation International, using method of Tabor and Williams (2010)). Standard error (SE) for historical trends; standard deviation (SD) for other variables.

	mean	SD/SE	units
Historical			
temperature annual average, Saguaro NP (1901-2002)	20.9	0.6	°C
temperature linear trend, Saguaro NP (1901-2002) [SE]	0.9	0.2	°C $century^{-1}$
temperature annual average, Tucson airport (1928-2007)	20.5	0.8	°C
temperature linear trend, Tucson airport (1928-2007) [SE]	2.6	0.4	°C $century^{-1}$
precipitation annual average, Saguaro NP (1901-2002)	270	90	mm y^{-1}
precipitation linear trend, Saguaro NP (1901-2002) [SE]	-2	11	% $century^{-1}$
precipitation annual average, Tucson airport (1928-2011)	280	80	mm y^{-1}
precipitation linear trend, Tucson airport (1928-2011) [SE]	-7	18	% $century^{-1}$
Projected (1990-2100)			
IPCC B1 scenario (lower emissions)			
temperature change in annual average	2.6	0.7	°C $century^{-1}$
precipitation change in annual average	-6	10	% $century^{-1}$
IPCC A1B scenario (medium emissions)			
temperature change in annual average	3.5	0.7	°C $century^{-1}$
precipitation change in annual average	-3	10	% $century^{-1}$
IPCC A2 scenario (higher emissions)			
temperature change in annual average	4.5	0.7	°C $century^{-1}$
precipitation change in annual average	-12	10	% $century^{-1}$

Figure 1.

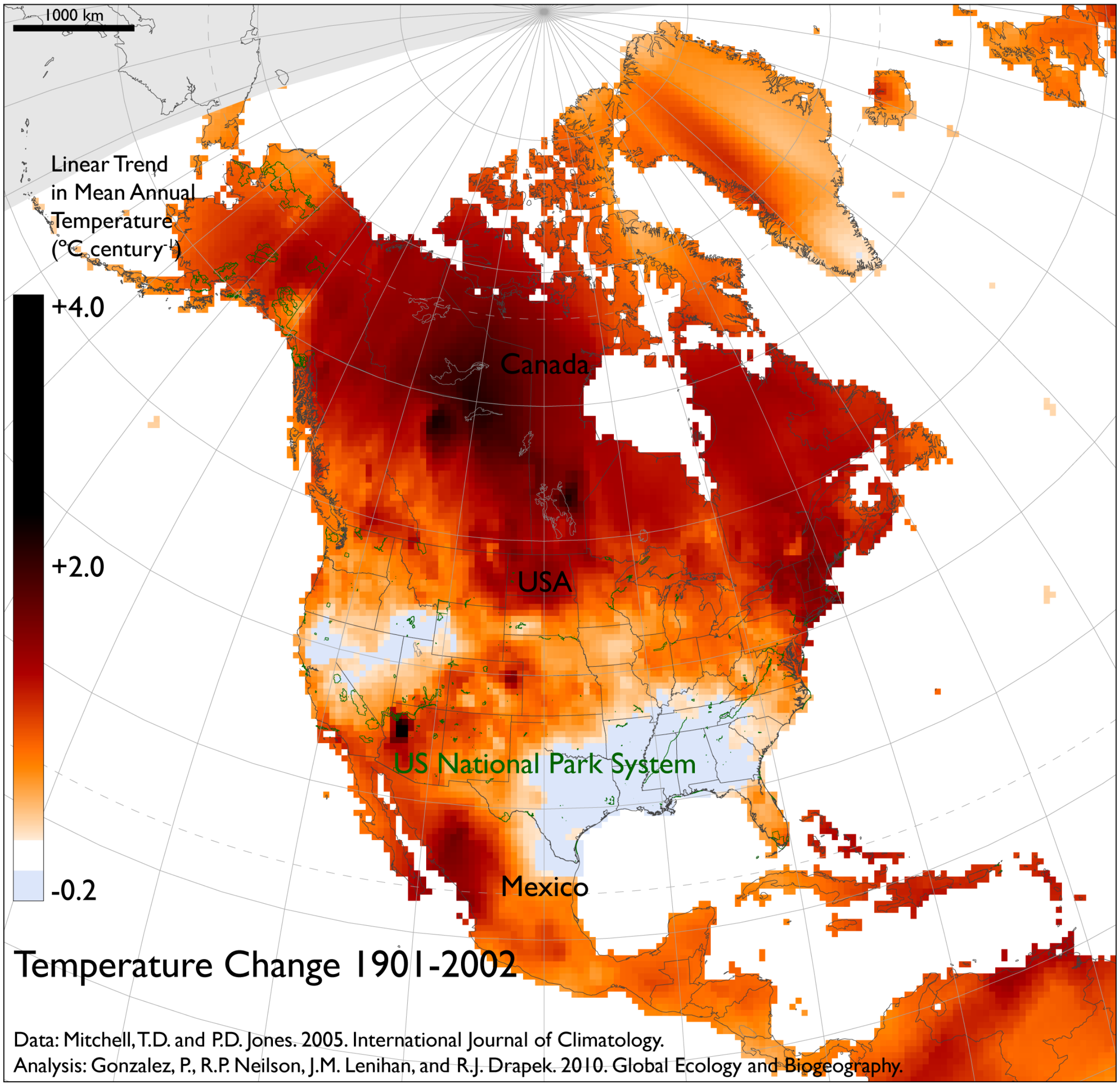

1000 km
Linear Trend
in Mean Annual
Temperature
(°C century⁻¹)
+4.0
+2.0
-0.2
Canada
USA
US National Park System
Mexico
Temperature Change 1901-2002
Data: Mitchell, T.D. and P.D. Jones. 2005. International Journal of Climatology.
Analysis: Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global Ecology and Biogeography.

Figure 2.

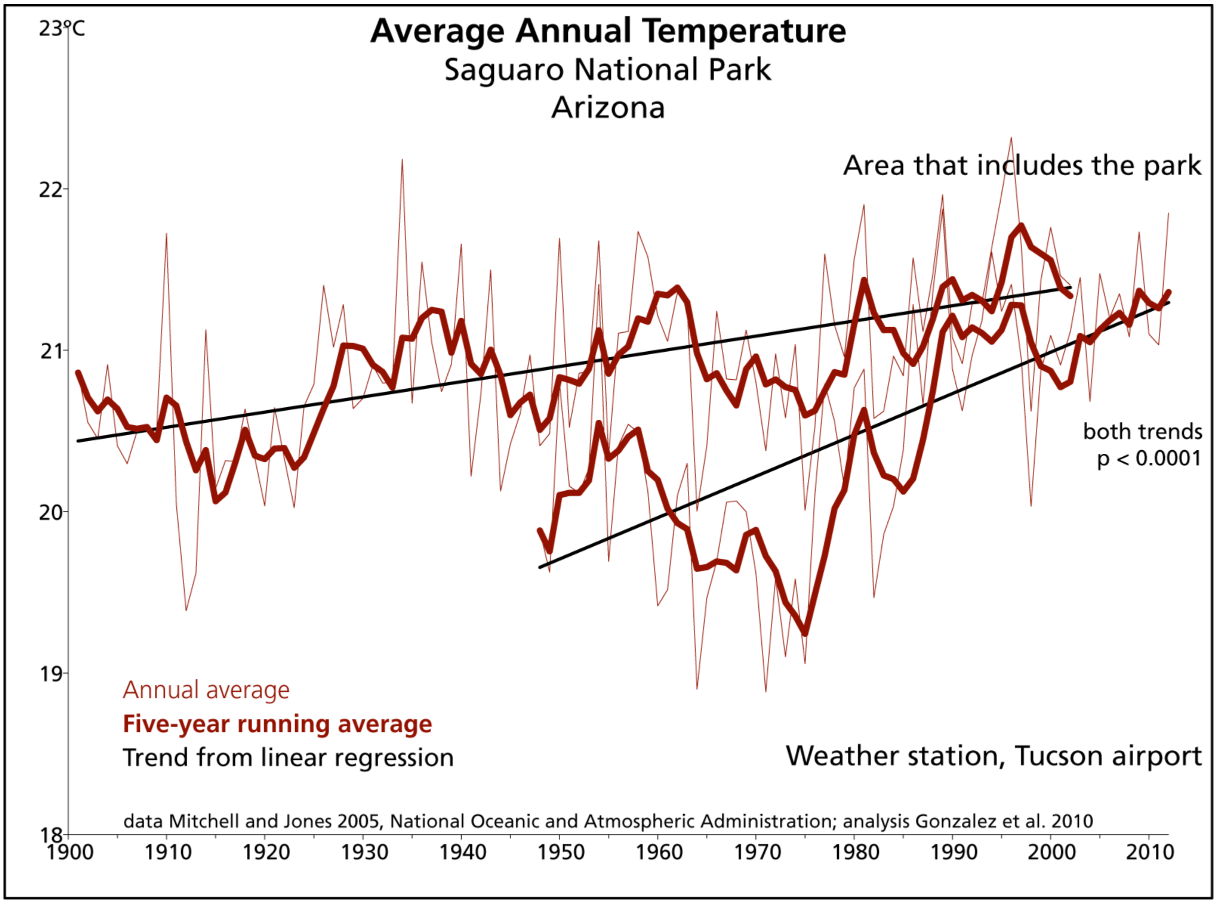
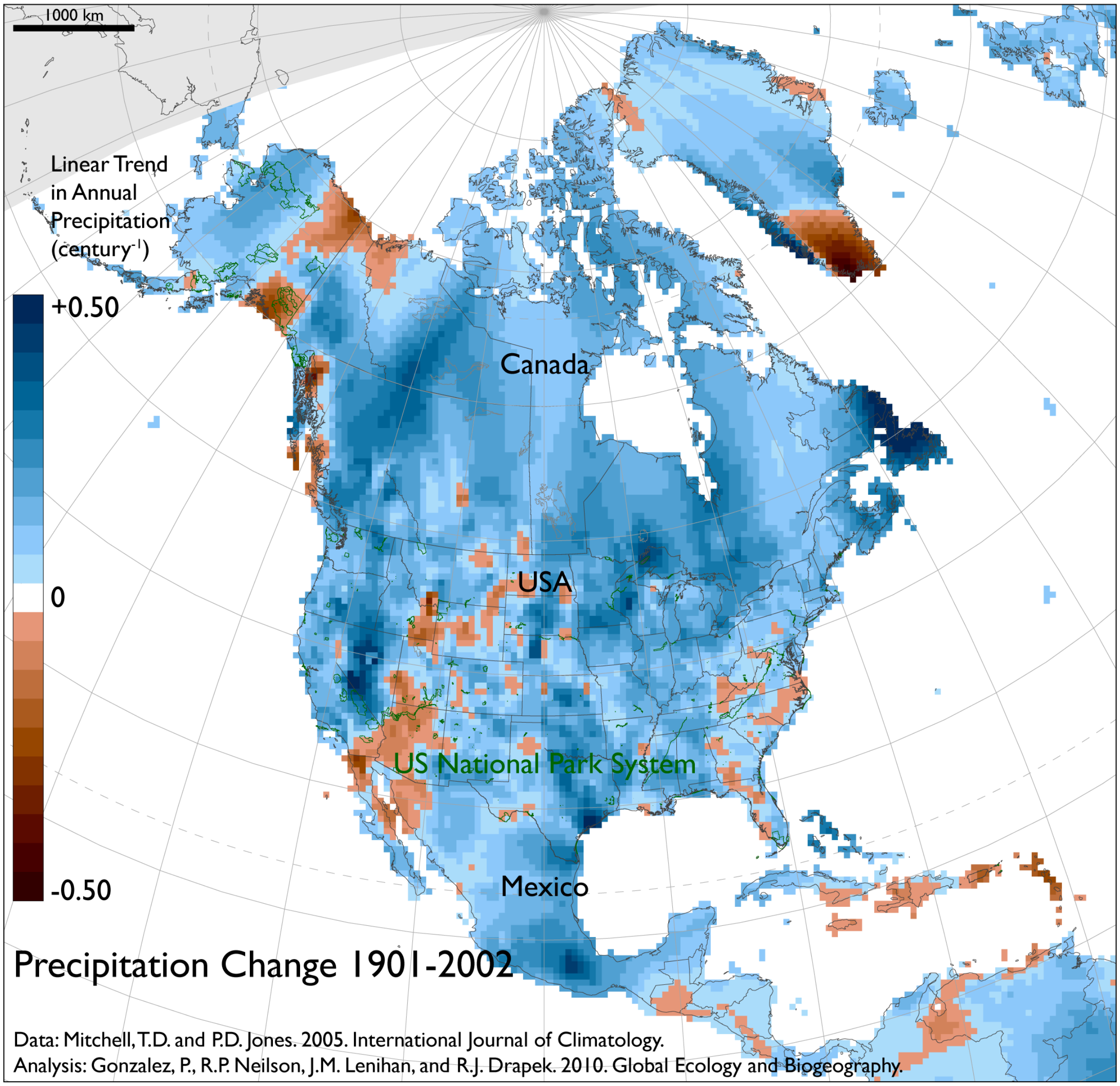

Average Annual Temperature
Saguaro National Park
Arizona
23°C
22
21
20
19
18
Area that includes the park
both trends
p < 0.0001
Annual average
Five-year running average
Trend from linear regression
Weather station, Tucson airport
data Mitchell and Jones 2005, National Oceanic and Atmospheric Administration; analysis Gonzalez et al. 2010
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 3.



1000 km
Linear Trend in Annual Precipitation (century^{-1})
+0.50
0
-0.50
Canada
USA
US National Park System
Mexico
Precipitation Change 1901-2002
Data: Mitchell, T.D. and P.D. Jones. 2005. International Journal of Climatology.
Analysis: Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global Ecology and Biogeography.

Figure 4.

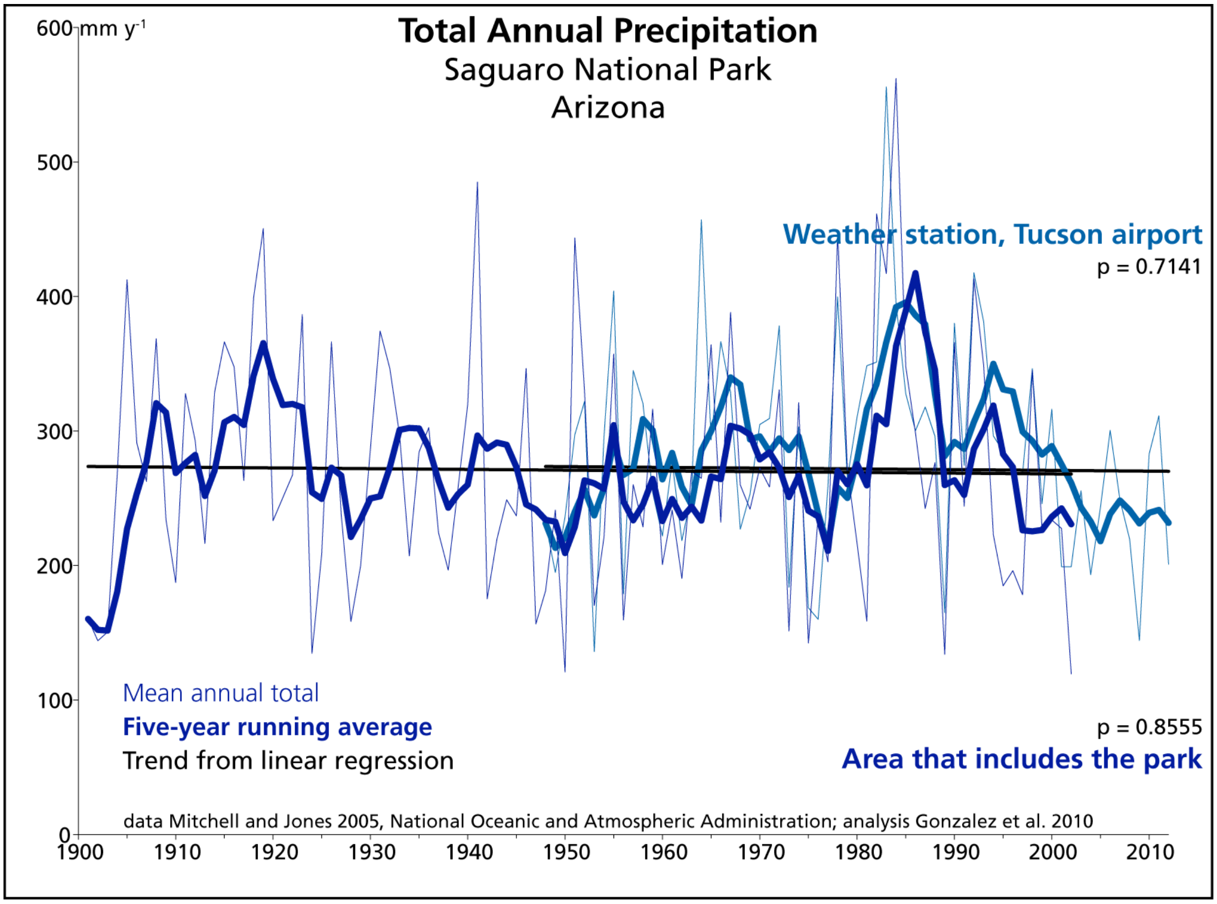
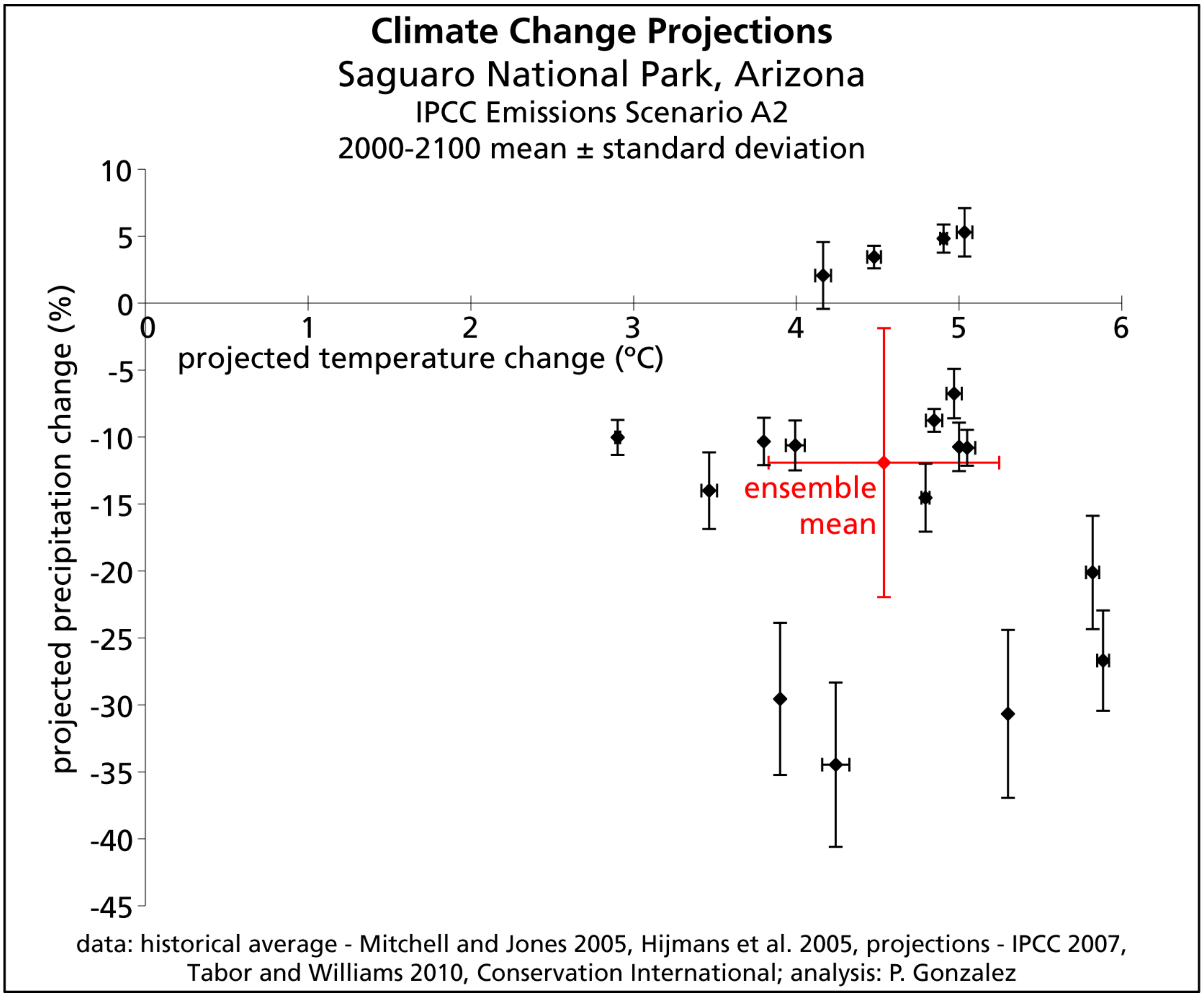

Total Annual Precipitation
Saguaro National Park
Arizona
600 mm y-1
500
400
300
200
100
0
Weather station, Tucson airport
p = 0.7141
Mean annual total
Five-year running average
Trend from linear regression
p = 0.8555
Area that includes the park
data Mitchell and Jones 2005, National Oceanic and Atmospheric Administration; analysis Gonzalez et al. 2010
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 5.



Climate Change Projections
Saguaro National Park, Arizona
IPCC Emissions Scenario A2
2000-2100 mean ± standard deviation
projected precipitation change (%)
projected temperature change (°C)
ensemble mean
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
0
1
2
3
4
5
6
data: historical average - Mitchell and Jones 2005, Hijmans et al. 2005, projections - IPCC 2007,
Tabor and Williams 2010, Conservation International; analysis: P. Gonzalez

References

Bonfils, C., B.D. Santer, D.W. Pierce, H.G. Hidalgo, G. Bala, T. Das, T.P. Barnett, D.R. Cayan, C. Doutriaux, A.W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and attribution of temperature changes in the mountainous western United States. Journal of Climate 21: 6404-6424.

Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography 19: 755-768.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Intergovernmental Panel on Climate Change (IPCC). 2007a. Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). 2007b. Climate Change 2007: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge, UK.

Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 5. Climate of the Southwest U.S. National Oceanic and Atmospheric Administration, Technical Report NESDIS 142-5, Washington, DC.

Le Quéré, C., R.J. Andres, T. Boden, T. Conway, R.A. Houghton, J.I. House, G. Marland, G.P. Peters, G.R. van der Werf, A. Ahlström, R.M. Andrew, L. Bopp, J.G. Canadell, P. Ciais, S.C. Doney, C. Enright, P. Friedlingstein, C. Huntingford, A.K. Jain, C. Jourdain, E. Kato, R.F. Keeling, K. Klein Goldewijk, S. Levis, P. Levy, M. Lomas, B. Poulter, M.R. Raupach, J. Schwinger, S. Sitch, B.D. Stocker, N. Viovy, S. Zaehle, and N. Zeng. 2013. The global carbon budget 1959–2011. Earth System Science Data 5: 165-185.

Littell, J.S., D. McKenzie, D.L. Peterson, and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications 19: 1003-1021.

Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25: 693-712.

Munson, S.M., R.H. Webb, J. Belnap, J.A. Hubbard, D.E. Swann, and S. Rutman. 2012. Forecasting climate change impacts to plant community composition in the Sonoran Desert region. Global Change Biology 18: 1083-1095.

Olsson, A.D., J.L. Betancourt, M.A. Crimmins, and S.E. Marsh. 2012. Constancy of local spread rates for buffelgrass (*Pennisetum ciliare* L.) in the Arizona Upland of the Sonoran Desert. Journal of Arid Environments 87: 136-143.

Pierson, E.A., R.M. Turner, and J.L. Betancourt. 2013. Regional demographic trends from long-term studies of saguaro (*Carnegiea gigantea*) across the northern Sonoran Desert. Journal of Arid Environments 88: 57-69.

Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. BioScience 58: 501-517.

Raupach, M.R., G. Marland, P. Ciais, C. Le Quéré, J.G. Canadell, G. Klepper, and C.B. Field. 2007. Global and regional drivers of accelerating CO_2 emissions. Proceedings of the National Academy of Sciences of the USA 104:10 288-10 293.

Tabor, K. and J.W. Williams. 2010. Globally downscaled climate projections for assessing the conservation impacts of climate change. Ecological Applications 20: 554-565.